Measurement of Hyperion MTF from On-Orbit Scenes

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***Abstract* – The Hyperion instrument was launched November 21, 2000 mounted on the EO-1 spacecraft into orbit 1 minute behind Landsat 7. Hyperion has a 7.5 km swath width, a 30 meter ground resolution and more than 220 spectral bands. Part of the on-orbit characterization involves MTF measurements from several ground scenes. These scenes included edges from the moon and glaciers as well as several bridges. The scenes were processed to determine the MTF for both the VNIR and SWIR imaging spectrometers and were compared to measurements made prior to launch.**

I. INTRODUCTION

The MTF is a measure of spatial resolution for an imaging system. On-orbit imaging system MTF has been determined from imagery of bridges in [1] and [2]. The edge technique for measuring MTF is described by [3] and has been demonstrated in the lab [4] and is utilized to measure MTF from on-orbit scenes. The edge method develops the Edge Spread Function (ESF) by interlacing multiple adjacent scans from an object that is at a slight angle to the satellite direction. The Line Spread Function (LSF) is determined with two methods: a curve-fit technique and a band-limited derivative. The MTF is obtained by processing the LSF with the Fourier Transform. The bridge method develops the LSF directly from multiple adjacent scans similar to the edge method. The LSF is then processed with the Fourier Transform and adjusted by the bridge width to obtain the MTF.

II. HYPERION MTF REQUIREMENT

The MTF requirement is dependent on the wavelength as shown in Table I. The requirement is specified at the Nyquist frequency.

TABLE I. HYPERION MTF REQUIREMENT

	VNIR MTF			SWIR MTF			
λ (mm)	0.45	0.63	0.90	1.05	1.25	1.65	2.20
Req.	0.20	0.20	0.15	0.14	0.14	0.15	0.15

The measured in-track MTF is shown in Table II. The in-track MTF is calculated from the measured cross-track MTF by multiplying by $2/\pi$.

TABLE II. PRE-FLIGHT MEASURED MTF

λ (μm)	FOV > 200	Center FOV	FOV < 20
0.5	0.29	0.27	0.22
0.63	0.27	0.28	0.22
0.90	0.24	0.26	0.22
1.05	0.28	0.3	0.28
1.25	0.28	0.3	0.27
1.65	0.27	0.27	0.25
2.2	0.28	0.27	0.23

III. MTF EXAMPLES

A. *Edge Method using Ross Ice Shelf*

The image in Fig. 1 is of the Ross Ice Shelf on January 16, 2001. This Hyperion image is from band 28 (λ = 630 nm). This image was used to determine the in-track MTF. The edge angle is larger than desired but this effect was removed from the final MTF result.

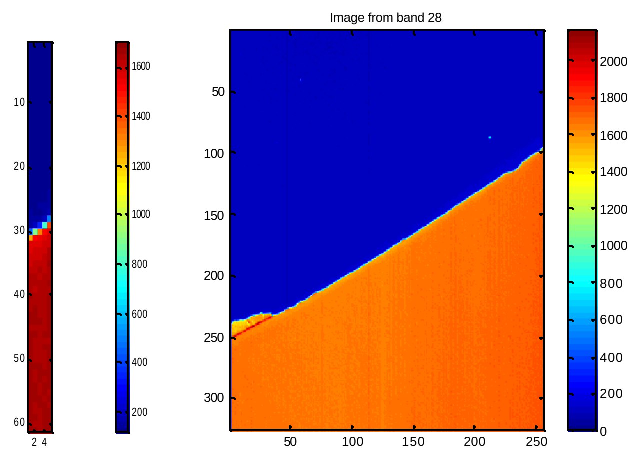

Fig. 1 Ross Ice Shelf Image for MTF Processing

The adjacent field pixels were interlaced to produce the ESF shown in Fig. 2.

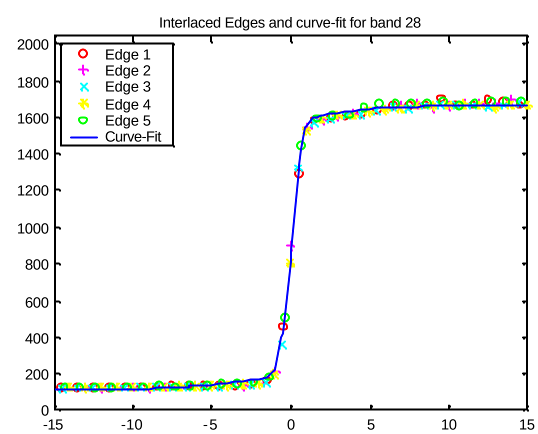

Fig. 2. Interlaced ESF and Curve-fit

The interlaced ESF was developed by performing a curve-fit to each field pixel scan of the edge. A curve-fit of a error function was then fit to the interlaced curve-fit. The LSF is directly determined from the curve-fit parameters.

The edge was also processed without a curve-fit by using a band-limited derivative and a Hanning window. The edge from each field pixel was located using a centroid algorithm to produce the ESF. The ESF was processed with the derivative filter to produce the LSF. The LSF is then multiplied by a Tukey window [5] that is centered on the LSF to reduce the influence of the noise outside the edge from affecting the MTF. Fig. 3 shows the initial edge, LSF from the curve-fit, LSF from the derivative and Tukey window.

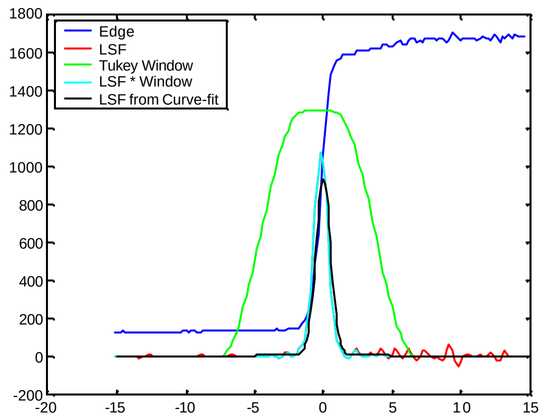

Fig. 3. Resulting LSF from ESF.

The LSF is processed with Fourier transform to produce the MTF. The MTF is then adjusted for the edge slope. The edge slope in this case is approximately 0.5. This would make a perfect edge (minimal optical LSF) an additional 0.5 pixels wide therefore reducing the MTF. This is similar to a bridge with a width of 0.5 pixels so the resulting MTF is adjusted by a sinc function. This amount of the edge angle degrades the MTF at Nyquist by 2%. The resulting MTF for both the curve-fit and derivative method are shown in Fig. 4. The MTF at Nyquist from this scene is between 0.25 and 0.28 while the ground measurement was 0.28.

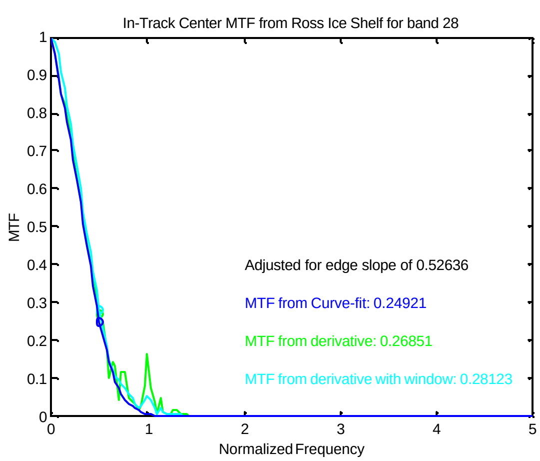

Fig. 4. Calculated MTF from LSF.

B. Bridge Method using Mid-Bay Bridge

The image in Fig. 5 is a picture of the Mid-Bay bridge near Eglin AFB and Destin, Florida. The Hyperion image was acquired on December 24, 2000. This image will be used to measure cross-track MTF. The left picture is a close-up of the bridge from band 30 (λ = 0.650 μm). The right image is a color composite from three Hyperion bands (Red = Band 28, Green = Band 21, Blue = Band 16). The angle between the bridge and the spacecraft direction is too small to use consecutive frames so every 5th frame is used.

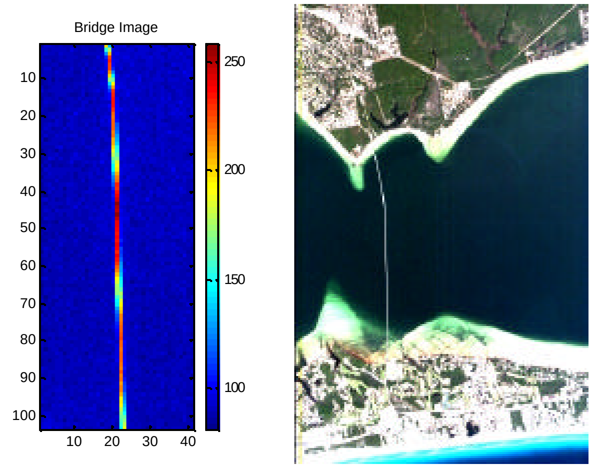

Fig. 5. Mid-Bay Bridge for MTF Processing

The frames are processed to determine the location of the bridge. This allows the frames to be interlaced to completely describe the LSF. The LSF is then processed with a curve-fit to a double Gaussian. In Fig. 6 the curve-fit is shown with the interlaced frames.

The LSF is processed with a Fourier transform and adjusted by the bridge width to determine the MTF. The bridge width is only 13.02 meters which adjusts the MTF by only 3% at the Nyquist frequency. The MTF is shown in Fig. 7. The MTF at Nyquist from this scene is between 0.39 and 0.42 while the ground measured value was 0.42.

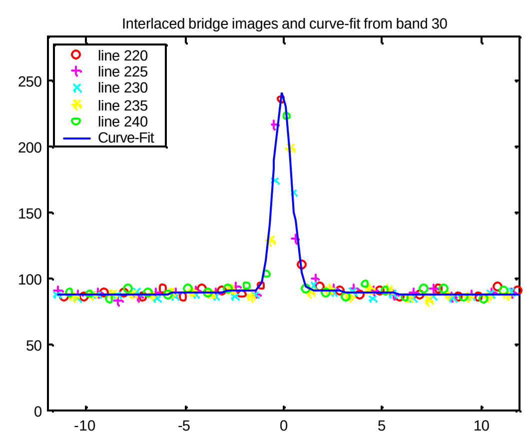

Fig. 6. Interlaced LSF and Curve-fit

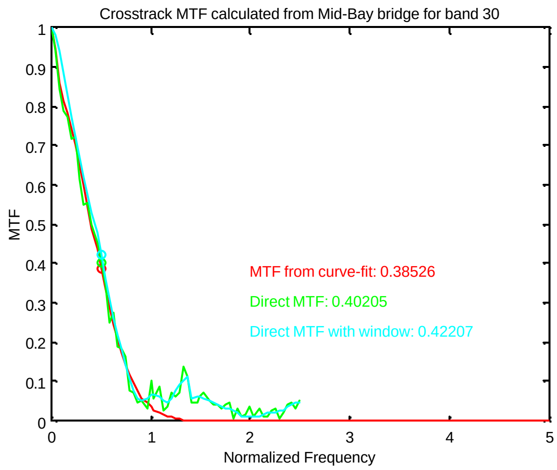

Fig.7. Calculated MTF from LSF

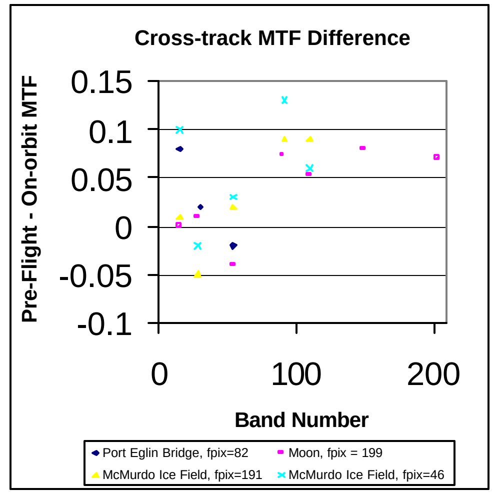

Fig. 8. Cross-Track MTF Measurements

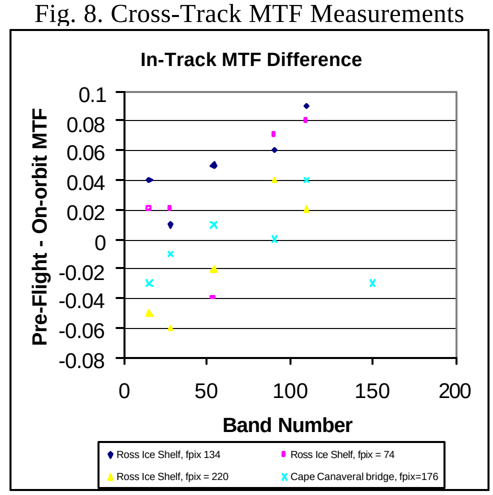

Fig. 9. In-Track MTF Measurements

IV. Comparison with Pre-Flight Measurements

Fig. 8 shows the difference between the cross-track MTF for ground and on-orbit measurements. The average difference is 3.9% and the standard deviation is 5.0%. Fig. 9 shows the difference between the in-track MTF for pre-flight and on-orbit measurements. The average difference is 1.47% and the standard deviation is 4.3%. In general the difference between the ground and on-orbit measurements were less for bridges than for edges. For example a bridge near Cape Canaveral was almost an entire GSD wide but the results were very similar to the pre-flight measurements over the entire spectrum.

V. Conclusions

This paper has described the MTF measurements that have been performed using on-orbit imaging from the Hyperion imaging spectrometer. The MTF was calculated for both edge and bridge objects with reasonable repeatability to the measurements on the ground. Bridge scenes produced excellent repeatability to the ground measurements while the edge scenes offered challenges for continued algorithm development. Based on the average difference between the ground and on-orbit MTF measurements there has not been significant change due to the launch or operational environment.

Acknowledgements

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References

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